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USE OF SIMPLE TAPE RECORDERS FOR STORING DIGITALIZED ANALOG SIGNALS

S. Stots and M. Detterer

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16. Abstract

A method for long-term storage of digitalized analog signals on simple audio tape recorders of the cassette type is described. It can be used for continuous analog signals, as they have high redundancy. On playback, recording errors can be detected and largely corrected. The readout of stored digital data can take place in digital form as well as in analog form after suitable conversion. At readout the faulty or erroneous data are marked and the number of errors counted.

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USE OF SIMPLE TAPE RECORDERS FOR STORING DIGITALIZED ANALOG SIGNALS

S. Stots and M. Detterer

1. Summary

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Analog signals from measurements are being stored and processed in digital form more and more. Special magnetic tape equipment is usually used for the long-term storage of digital signals. A considerable technical effort is expended on these machines to keep the error rate as low as possible. When such machines are used, however, the fact is often overlooked that continuous analog signals exhibit such a high level of redundancy that small gaps in the signal curve do not appreciably impair the information content of the overall signal. A series of consecutive digital values are produced from the analog signal by digitalization (see Fig. 1). If occasional values are missing in this series, the overall curve of the original analog signal is not appreciably affected.

From the above point of view it has been possible to design a circuit which makes it possible to store continuous analog signals in digital form with inexpensive equipment. Any errors which arise are accepted in advance. When the stored data are played back later, erroneous digital values are recognized and deleted, the next correct value again appearing at its proper address. The gaps resulting from the deletion of erroneous values thus cannot shorten the signal curve (time error!). The measured signals stored on the basis of this concept can then be processed further on digital systems or be read out again as a curve after D/A conversion.

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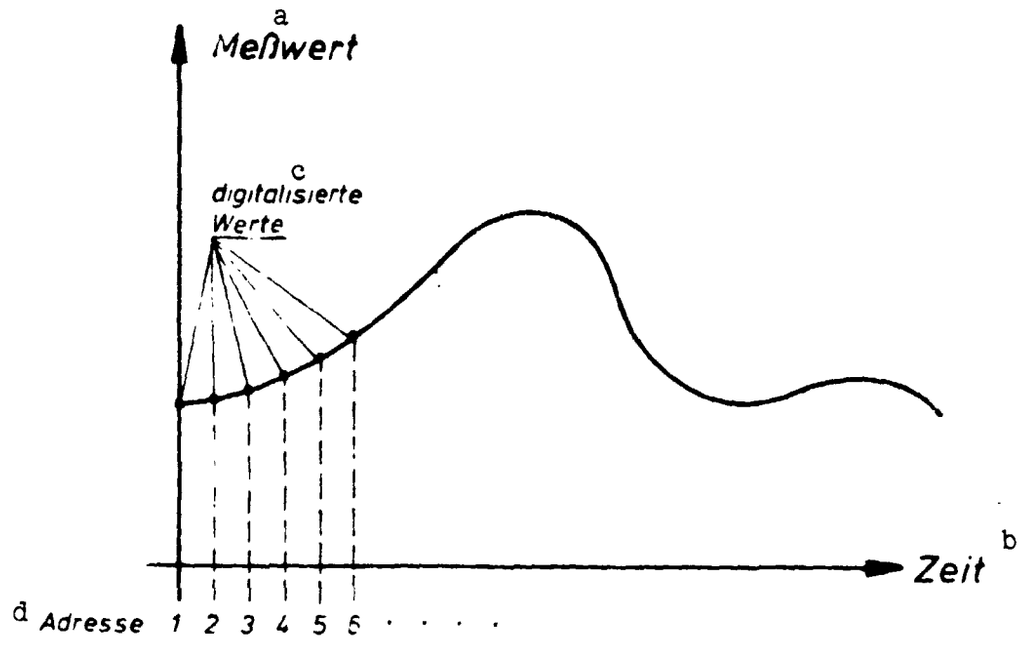

Fig. 1.

Key: a. Value of datum
b. Time
c. Digitalized values
d. Address

2. Explanation of Principle

The storage method described here pertains exclusively to digitalized, continuous analogs signals, since only these exhibit the necessary redundancy. In this case, a simple stereo cassette tape recorder can be used for storage, on which the digital data are recorded serially.

As a rule, the signal curve will be obtained as a continuous function of time. The following description refers to such time-dependent signals. Of course, a corresponding version of the description applies if the signal is a function of some other physical quantity than time.

Digitalization and storage of the time-dependent analog signal to be processed takes place in certain exactly defined time intervals (see Fig. 1). Addressing is sequential, i.e. the digital data are stored in the sequence of their occurrence. In Fig. 2, the stored digital data are shown schematically as a function of memory address. The value of the stored digital datum is plotted as the abscissa.

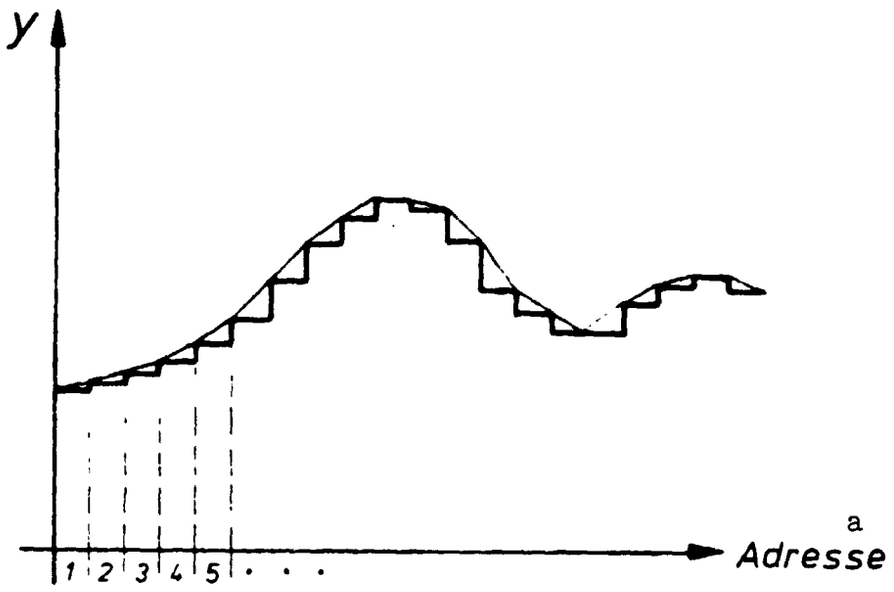

Fig. 2.

Key: a. Address

When the stored digital data are played back, they are recalled from the magnetic tape in the original sequence and are available for futher processing. For example, they can be shown on a plotter as a function of memory address in the form of an analog curve (see thin solid curve in Fig. 2).

It may be that the plot is disrupted at several points because /4 of the simple recording method used (drop-outs, recording head fouling, tape flutter, etc.). If such errors occur, the garbled

digital values are recognized upon playback and are prevented from being processed further. Through the use of a special coding system described later, it is possible to reconstruct the storage address associated with the next undisturbed digital word. This keeps the time curve from being distorted, for the individual addresses represent certain points in time along the continuous signal. The effect of an error point (absence of two words) is shown in highly exaggerated form in Fig 3 for illustrative purposes. If shown on a normal scale, the error point would be practically invisible (cf. the actual plot shown in Fig. 7).

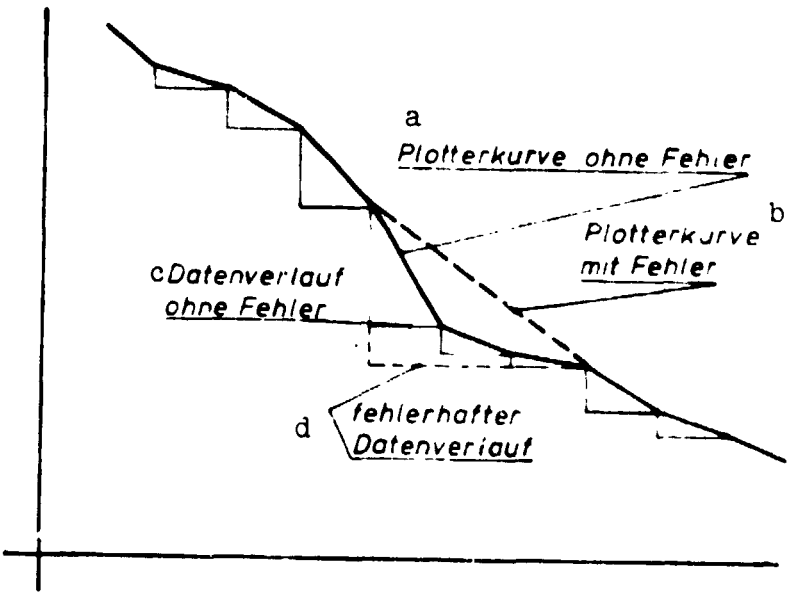

Fig. 3.

Key: a. Plotter curve without error
b. Plotter curve with error
c. Data curve without error
d. Erroneous data curve

The error frequency to be expected was determined in prolonged series of tests. Among other things, a plot with a total

of 66,000 digital words was studied. Of these, 50 words were found to be erroneous. This corresponds to an average error frequency of $7.5 \cdot 10^{-4}$.

3. Basic Design of a Magnetic Tape Storage System /5

3.1. Standardization

In order that the data storage idea described can be put into practice, it is necessary to establish standards on which to base the recording process. The following conventions have been agreed upon for the application at hand:

A simple stereo cassette tape recorder is used for storage.

Digital data occurring in parallel are converted into serial data prior to recording.

A data format of 10 bits per word is used. In addition to /6 these 10 bits, each word is assigned four address bits as an auxiliary address which is to allow correct address assignment after erroneous words.

The prepared data are recorded serially on one of the two stereo tracks on the tape. The complementary value of the data is recorded on the other stereo track in like manner. This is necessary for later error recognition.

The stored signals may contain no DC components, since the tape recorders used can operate only with AC signals.

Recording is done at a bit frequency of 2 kHz.

The pause between two words correspond to two bits in length.

The length of the recording of a measurement process is set at 2048 words.

3.2. Actual Design

A setup is described below which has proven itself at the Ernst Mach Institute for Shock Wave Research. It should be mentioned here that it does not exhaust all of the possibilities which could be realized on the basis of this idea.

Since systems had already been built in our institute for the digital acquisition and short-term storage of analog measurement signals [1, 2], it was merely necessary to provide for the long-term storage of digital data. To make overall operation easier to understand, all equipment components involved in magnetic tape recording and playback and in signal preparation will be described as a unit in the following.

The basic structure is shown in the block diagram (Fig. 5). The part pictured to the left of the dashed line shows data preparation and recording, while the part on the right describes data playback, error recognition and data output. /7

A fast A/D converter is used to prepare the analog signals which are measured. The digitalized analog values are temporarily stored in an MOS shift register, in the time sequence of their occurrence, for time transformation. The individual digital words have a 10 bit format; storage capacity is 2 k. The 2048 addresses in memory embody 2048 equal-length time intervals along the analog signal curve.

3.2.1. Recording

The arrangement of individual digital words in time must be precisely established for subsequent magnetic tape recording of

the stored data. It would be necessary here to record not only the data word but also the address, which of course contains the time sequence. Practical experience with this type of recording has shown that it is not necessary to register complete address information, since the observed recording errors are very infrequent. It was therefore determined that only an auxiliary address consisting of the four least significant address bits would be co-registered as the address part. Since relatively large groups of errors do not occur, this reduced address information is quite sufficient to allow the exact time sequence of data words to be reconstructed at error points on the recording.

Prior to recording, digital words occurring in parallel are arranged serially to allow them to be put on tape. So that not only the content of the recorded words but also their serial clocking can be reconstructed from the given information during later playback, both the direct digital signal (Fig. 6a) and its complementary value (Fig. 6b) are recorded. If the contents of the two tracks are added later, we obtain a continuous, uninterrupted series of 14 1-bits (Fig. 6i). If this series of bits /8 has gaps in it, the associated word is recognized to be erroneous.

Due to the variable DC component of the digital signals, it is not possible to record the signal form shown in Figs. 6a,b on an audio tape recorder. The signals are therefore transformed as shown in Figs. 6c,d. Fig. 4 shows the schematic for this. The DC components of the signal are eliminated by a differentiating stage (R1, C1). A low-pass stage (R2, C2) which follows it attenuates the steepness of the pulse edges, which would otherwise cause undesirable cross-talk between the two stereo channels of the tape recorder.

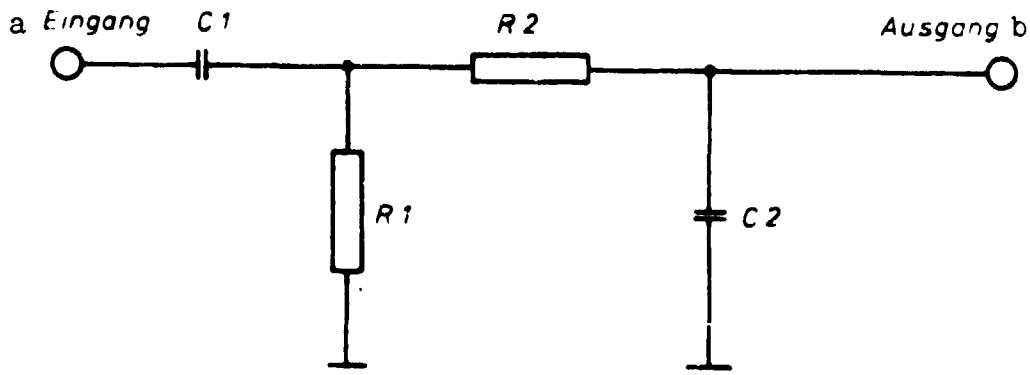

Fig. 4.

Key: a. Input
b. Output

3.2.2. Playback /9

The digital pulses coming from the magnetic tape of course do not exhibit the form required for processing in TTL systems (Figs. 6e,f) and must be prepared accordingly. The two tracks are therefore first fed separately into a comparison circuit, followed by a Schmitt trigger, which compares the arriving pulses with a reference level and delivers distinct output pulses for further processing (Figs. 6g,h). The two tracks are then added, the sum being used, among other things, for clocking in series/ /parallel conversion (Fig. 6i).

The stored information is now available for further parallel processing. A clocking signal for a satisfactory word must contain 14 1-bits at an interval of 0.5 ms from bit to bit. If these conditions are not satisfied, the particular word is erroneous, and the circuit for timing monitoring delivers an error recognition signal. The data bits in this word are not transmitted to the buffer in this case. On the other hand, all addresses in main storage not used because of erroneous words are filled up in order to maintain the sequence of data flow. This process is controlled by the auxiliary (four-bit) address added to the data

word and causes forced synchronization with the sequential addressing process of the main storage unit. At the same time, the error recognition system is stored in main storage as an eleventh bit, indicating the addresses with erroneous words. These addresses are counted in a special counter and indicated as the number of errors for the purpose of monitoring.

Since each auxiliary address contains only four bits, for reasons of simplification, it is only possible to reconstruct missing addresses if fewer than 16 erroneous words occur in succession. Practical experience shows that this case never occurs, so this simplification is justified.

The main storage unit consists of a shift register in which 2048 words of 11 bits each can be stored in paralle. Addressing is sequential, as used in a shift register. /10

The digital words stored in main storage are available for any further processing. If the original analog signal is to be read out as an analog curve, a plotter can be connected. Deflection in the x-direction is determined by an address counter for the sequentially addressed main storage unit; the stored data words of 10 bits each yield deflection in the y-direction. The error recognition signal, which is also stored, is used here to stop the plotter at error points and only start again at a new address occupied by a nonerroneous word.

An x-y recorder can also be used in place of a plotter if a suitable digital/analog converter is used for addresses and data. The error recognition system stored as the eleventh bit in main storage can be fed to a marker as the curve is being plotted, to indicate error points in the curve. From this we can see whether points of great information value have been disturbed in the curve.

A practical example of error elimination is shown in Fig. 7. Artificial errors have been added to a signal recorded without error (Fig. 7b). The curve of the erroneous, uncorrected signal can be seen in Fig. 7d. Fig. 7c shows the same erroneous signal after error correction by the method described here.

As can be seen, the built-in error correction is very effective, particularly in view of the fact that the artifical errors were generated in a disproportionately large number for the sake of clearer representation. The erroneous words are distributed as follows over the five error points: 2 - 2 - 11 - 1 - 1.

The trace of the error marker (Fig. 7a) gives the locations of errors which occur. Without this special labelling of errors, there would be practically no possibility of identifying error points on the curve in a normal situation. Thanks to the outstanding effectiveness of error correction, though, error marking along the curve could be dispensed with in most cases.

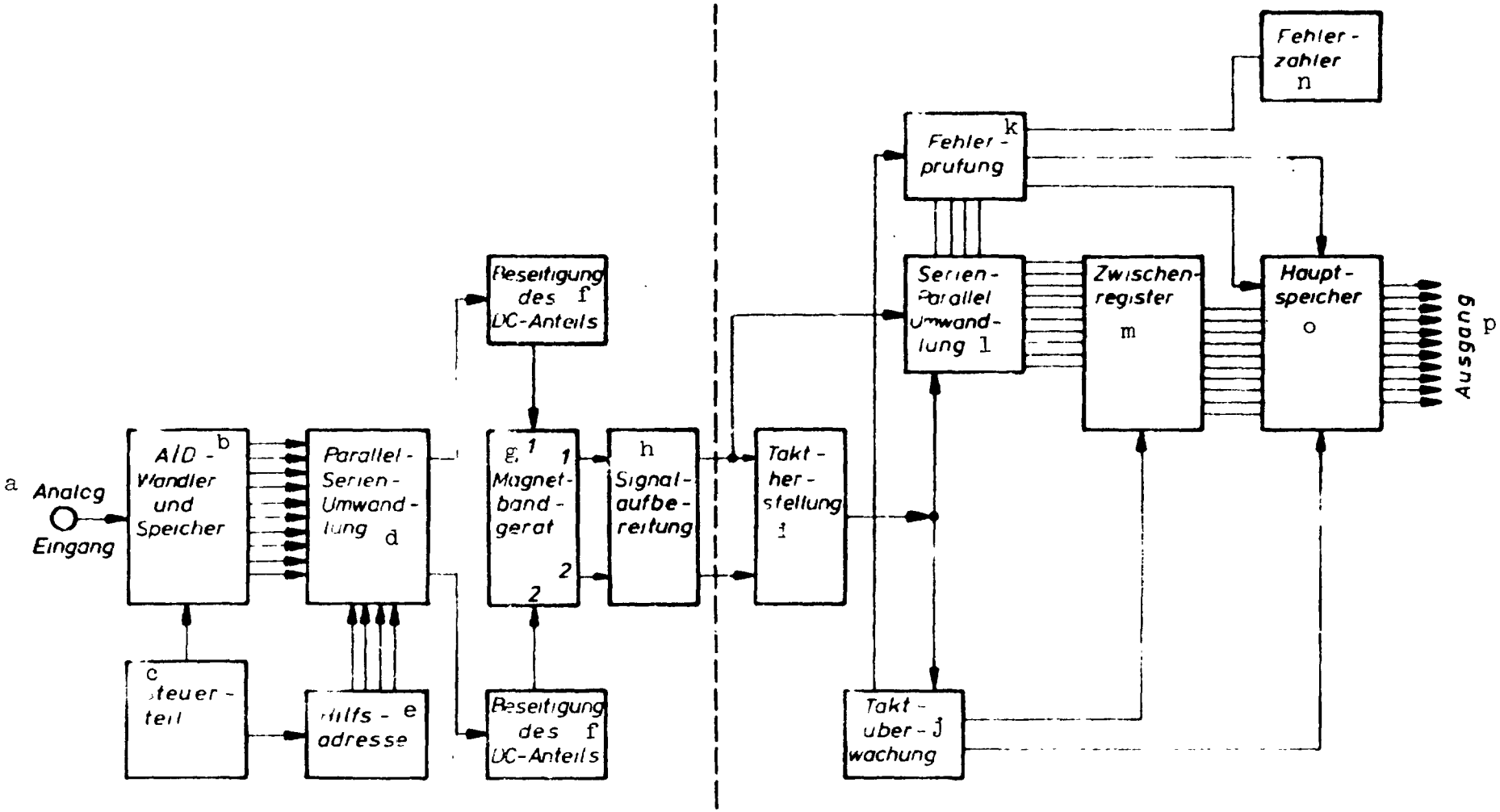

Fig. 5.

Key: a. Analog input; b. A/D converter and storage; c. Control unit; d. Parallel/series conversion; e. Auxiliary address; f. Elimination of DC component; g. Magnetic tape recorder; h. Signal preparation; i. Timing; j. Timing monitor; k. Error testing; l. Series/parallel conversion; m. Intermediate register; n. Error counter; o. Main storage; p. Output

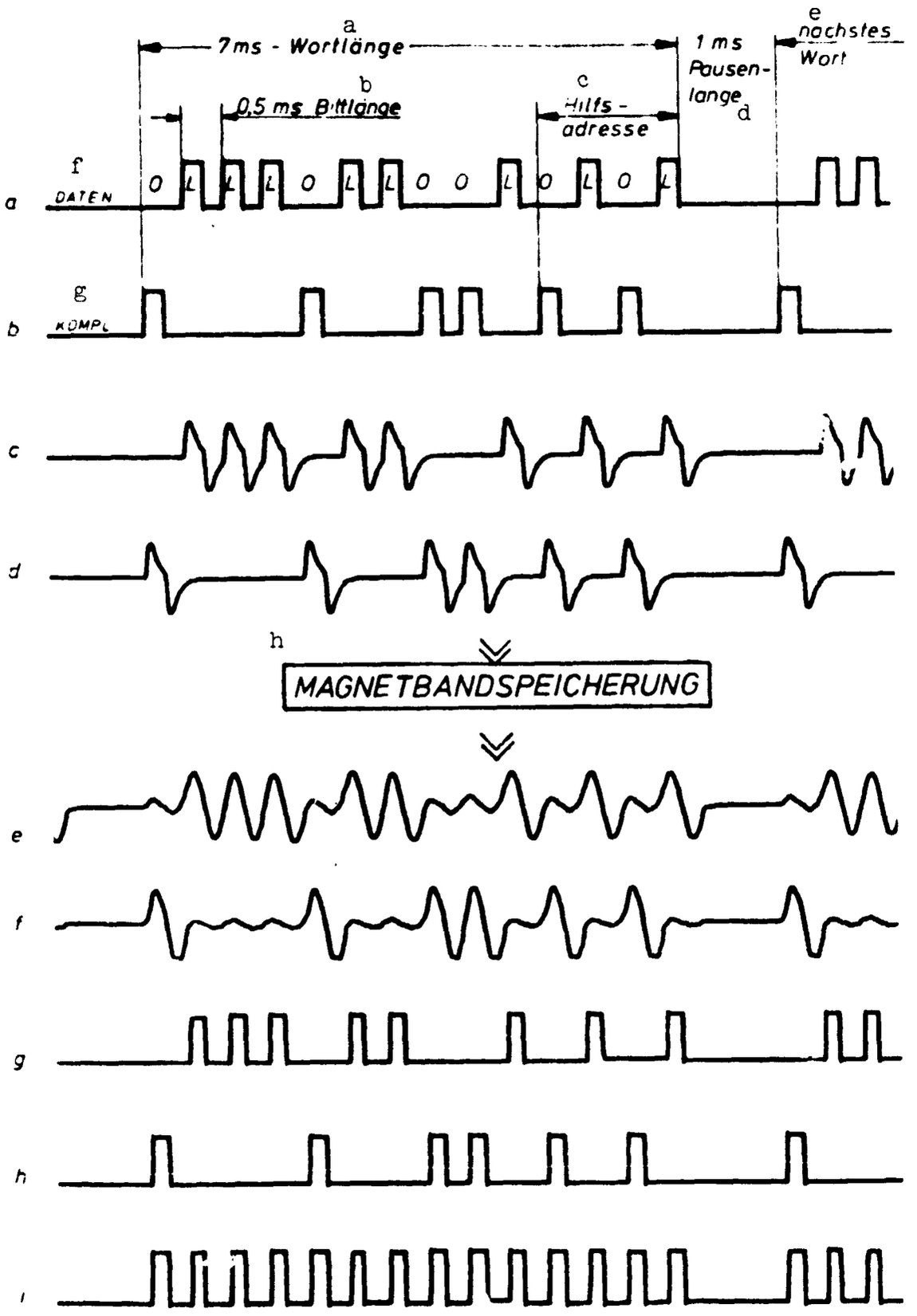

Fig. 6.

Key: a. Word length; b. Bit length; c. Auxiliary address; d. Pause length; e. Next word; f. Data; g. Complement; h. Magnetic tape storage.

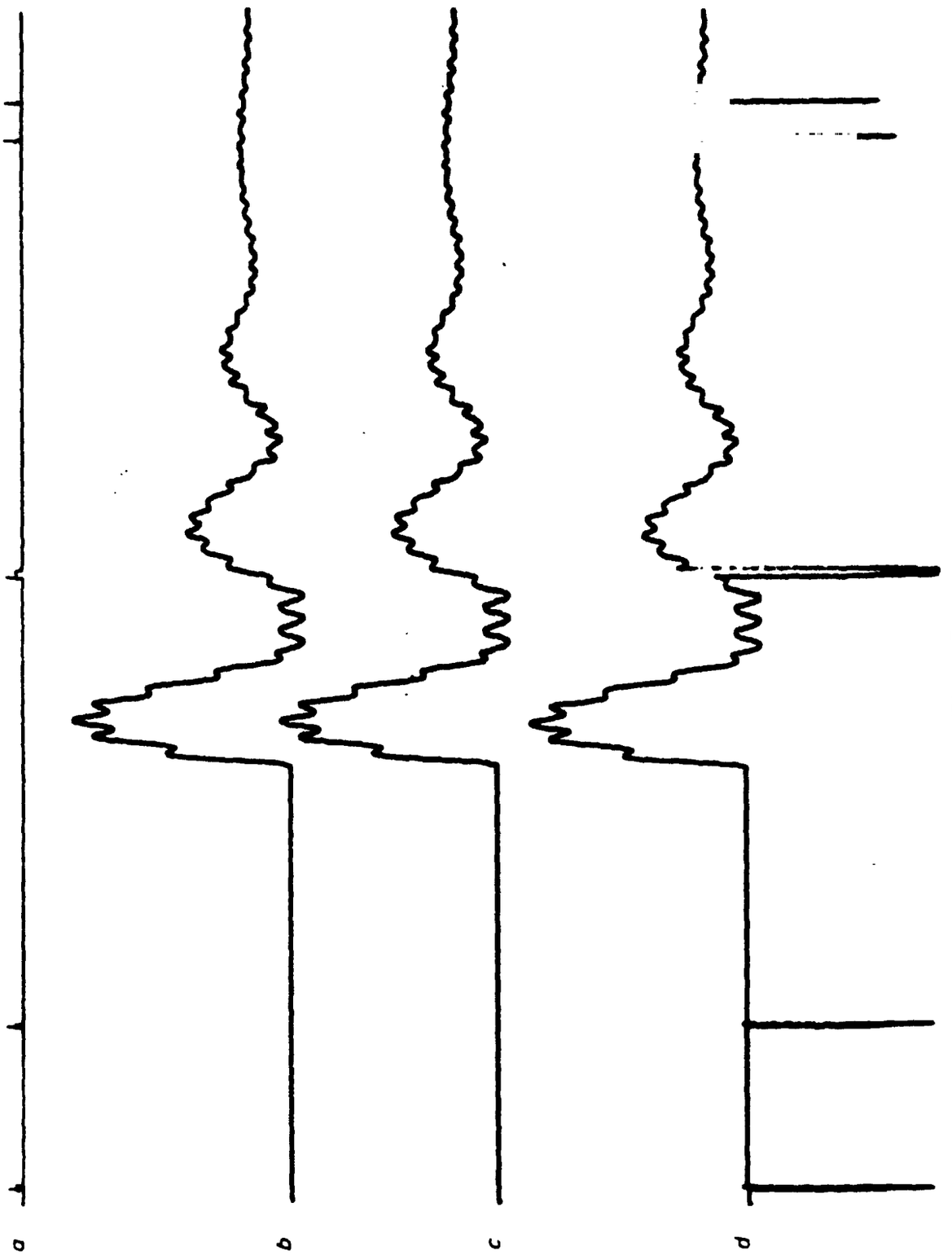

Fig. 7.

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